



The South Pole Earthshine Project

(A Proposal to the National Science Foundation Office of Polar Programs)

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Project Description

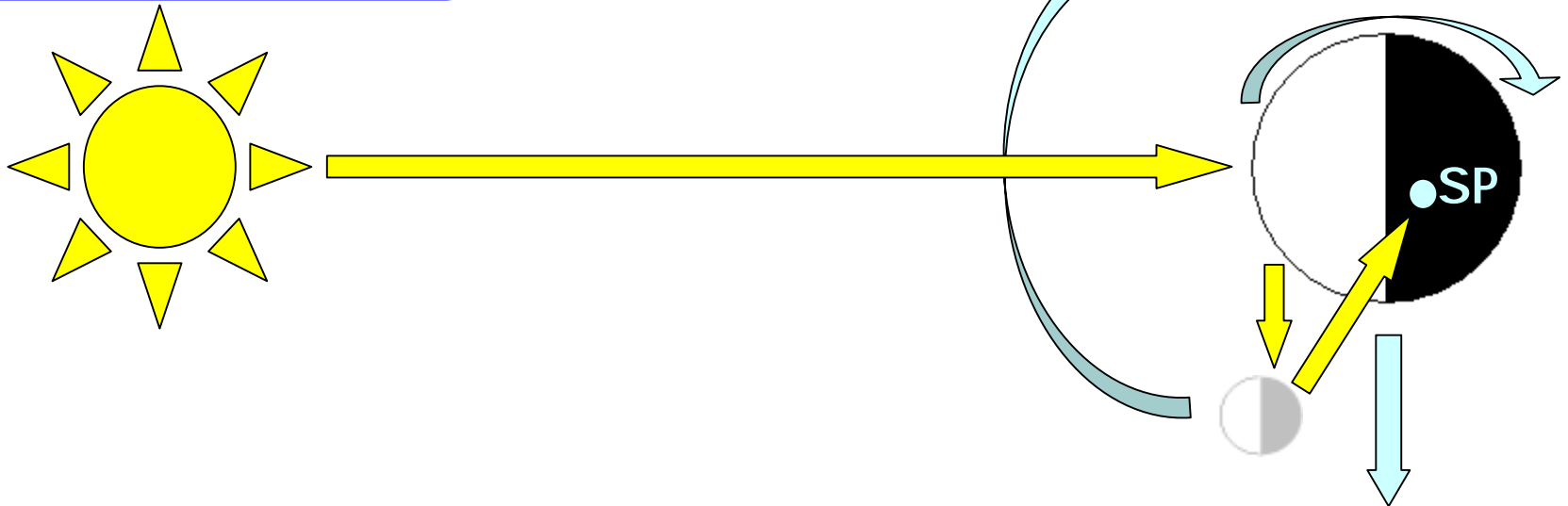
Motivation

- NASA's Terrestrial Planet Finder program explored many options
 - now views TPF Coronagraph (TPF-C) as most promising initial approach to observe extrasolar Earth-like planets
- TPF-C will discover and characterize such planets by directly detecting these distant point sources at visible wavelengths
- To refine optimum TPF-C design and observation concepts we need to see how Earth-like planets would appear as a single pixel, by measuring Earth's integrated visible-light phenomenology
- Phenomenology of interest includes indicators of Earth's
 - rotation rate • clouds and weather • annual seasons
 - oceans and continents • signs of habitability/habitation
- Experiment description and its benefits are exciting and easy to understand, this project will generate much public interest

Nature of Earthshine

• Half a millennium ago Leonardo da Vinci described Earthshine as a reflection path, (Sun to Earth to Moon to Earth) although he thought the main contributor was light reflected to the moon from Earth's oceans at sunrise or sunset

Earthshine,
from the
"dark side" of
the moon



Rationale

- People have begun to carefully measure Earthshine at crescent and half-moon lunar phases, calibrating against the bright moon signal
 - A spatially-integrated Earth spectrum similar to that of an extrasolar terrestrial planet to be viewed by TPF-C
 - Much greater accuracy than assembling small-FOV satellite data
 - Refines and validates predictive models
- Continuous time-dependent Earth spectrum measurements over several days, using a single instrument to measure light from the rotating Earth
 - No need to calibrate separate instruments at many longitudes under different air mass and weather conditions
- South Pole during its late autumn and mid winter (Sun well below horizon) is only stable location from which a ground telescope can view Earthshine continuously several days at a time (multiple full Earth rotations)
- South Pole atmosphere is extremely cold, dry, and thin
 - fully clear > 2/3 of the time, free from weather variations
 - yields transparency stability needed for accurate spectral data

Earth Science Benefits Too

- Spectra collected may also assist current investigations of Earth albedo variations → implications for climate change
- Ground-based Earthshine measurements indicate global sunlight decrease ~ 10 percent (late 1950's to early 1980's) The 80's and 90's had a global brightening. Now it's turned, resuming "global dimming" (a mystery -- see below.)
- Solar output flux varies only slightly, so scientists think global dimming results from air pollution
 - Less polluted regions often show little or no dimming
 - Possible contributors: airborne soot particles; water droplets and thicker, darker clouds

Instrument

< 10 kg, with refracting telescope, grating spectrometer (0.45 – 1.0 μm , SNR = 100 in 100 s), CCD detector; self-calibrating

Data Sought

Variations (due to time and geography) in continuum reflectivity, in spectral features (including “red edge” from land plants), in cloud cover
-- all will help refine models

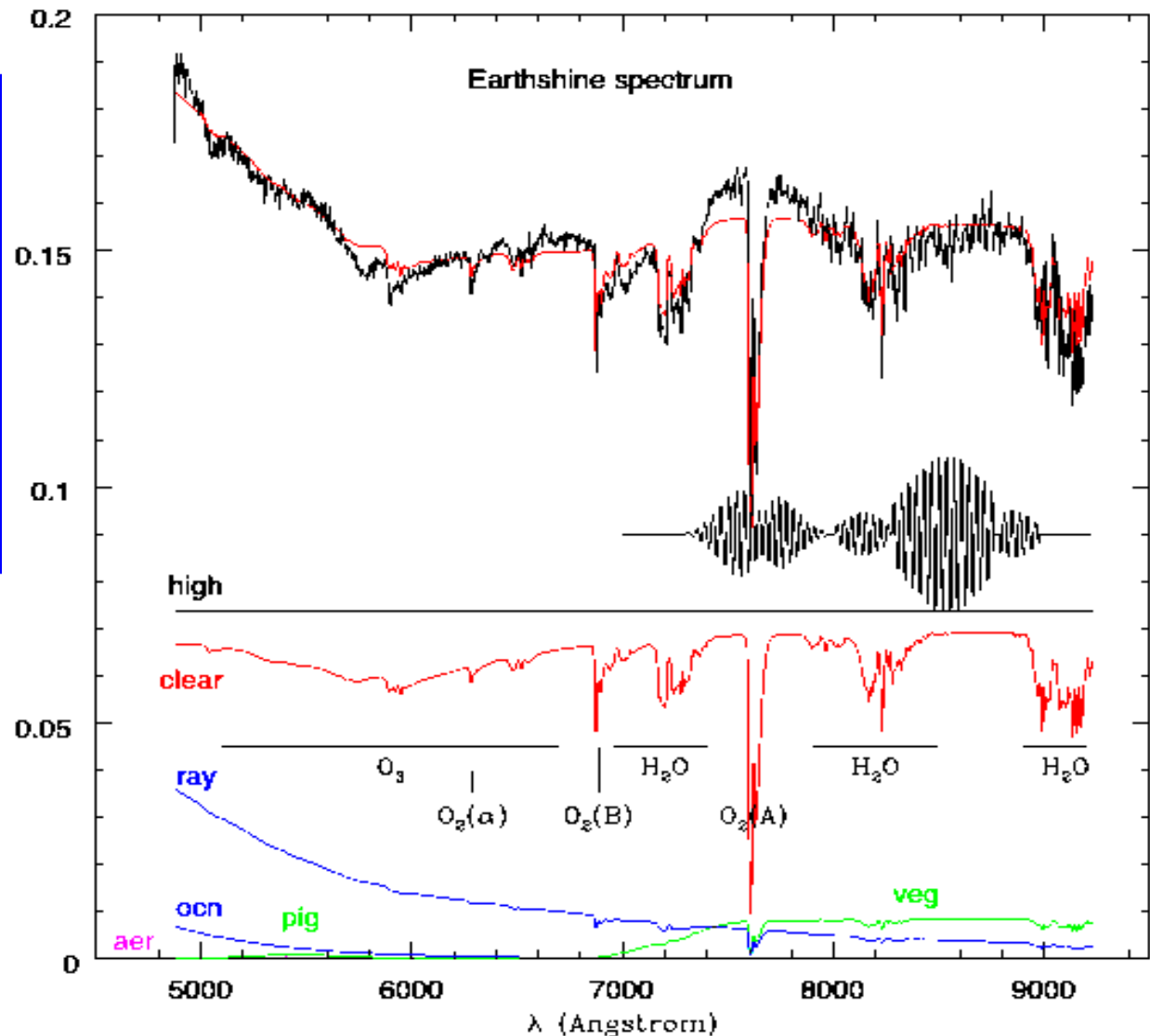
Challenges

- Scattered light control and compensation (bright part of moon outshines Earthshine by $\sim 10^4$)
- Pointing accurately to positions in Earthshine and bright-moon regions, for accurate lightcurves
- Remote telescope operation must be reliable in extreme cold (~ -60 C)

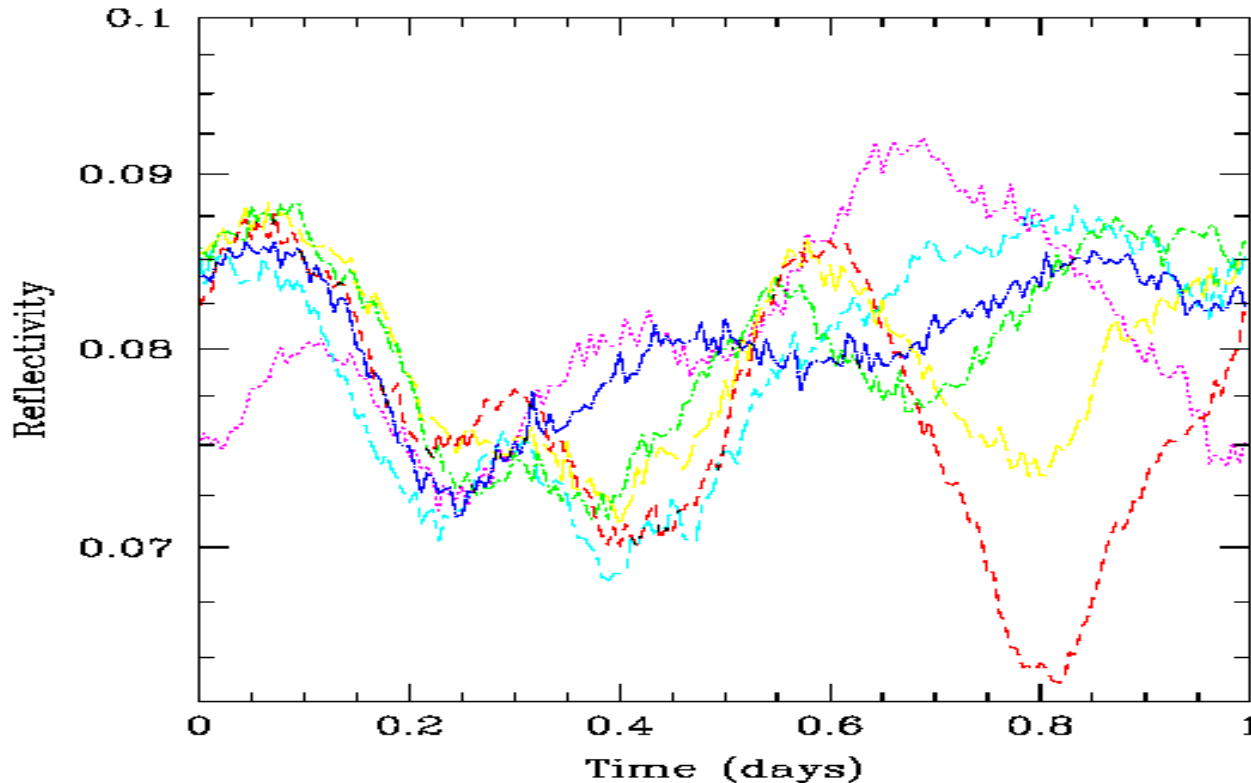
Earthshine Phenomenology

Spectrum of
Earthshine from
Tucson, Showing
H₂O, O₂, O₃,
Rayleigh
Scattering, and
'Red edge' of Plants

From "The Spectrum
of Earthshine: a
Pale Blue Dot
observed from the
ground" by N.J.
Woolf et al,
[Astrophys. J.](#), 574,
pp. 430-433, 2002.



Cloud Changes Alter Earth Rotation Lightcurve

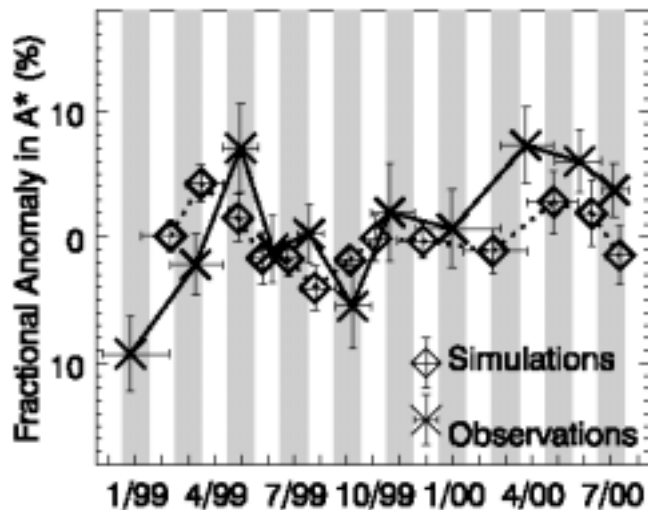


$\lambda = 0.55 \mu\text{m}$ lightcurves for 6 days, modeled for Earth-like planet at quadrature, using satellite cloud data

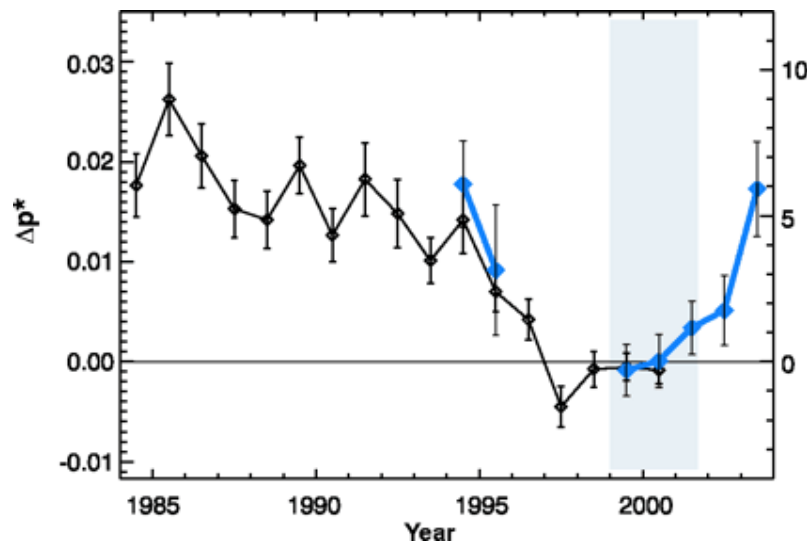
From "Characterizing Earth-like Planets with Terrestrial Planet Finder", by S. Seager et al, SPIE, 4835, pp. 79-86, 2002.

Improving Earth Reflectance Models Requires Better Data

A Project Earthshine study revealed Earth's albedo peaks during northern spring Earthshine excess in April and May about twice what computer models predicted based on satellite ice and cloud cover observations.



From "Earthshine Observations of the Earth's Reflectance," by P. Goode et al, Geophys. Res. Letters, 28, no. 9, pp. 1,671-1,674, 2001.



From "Changes in Earth's reflectance over the last two decades" by E. Pallé et al, Science, 304, pp. 1299-1301, May 28, 2004.

Recent albedo studies indicate decade-scale changes $>2\%$; our models don't explain this, but new spectral data might help.

Site Benefits

A Good Observing Facility Exists

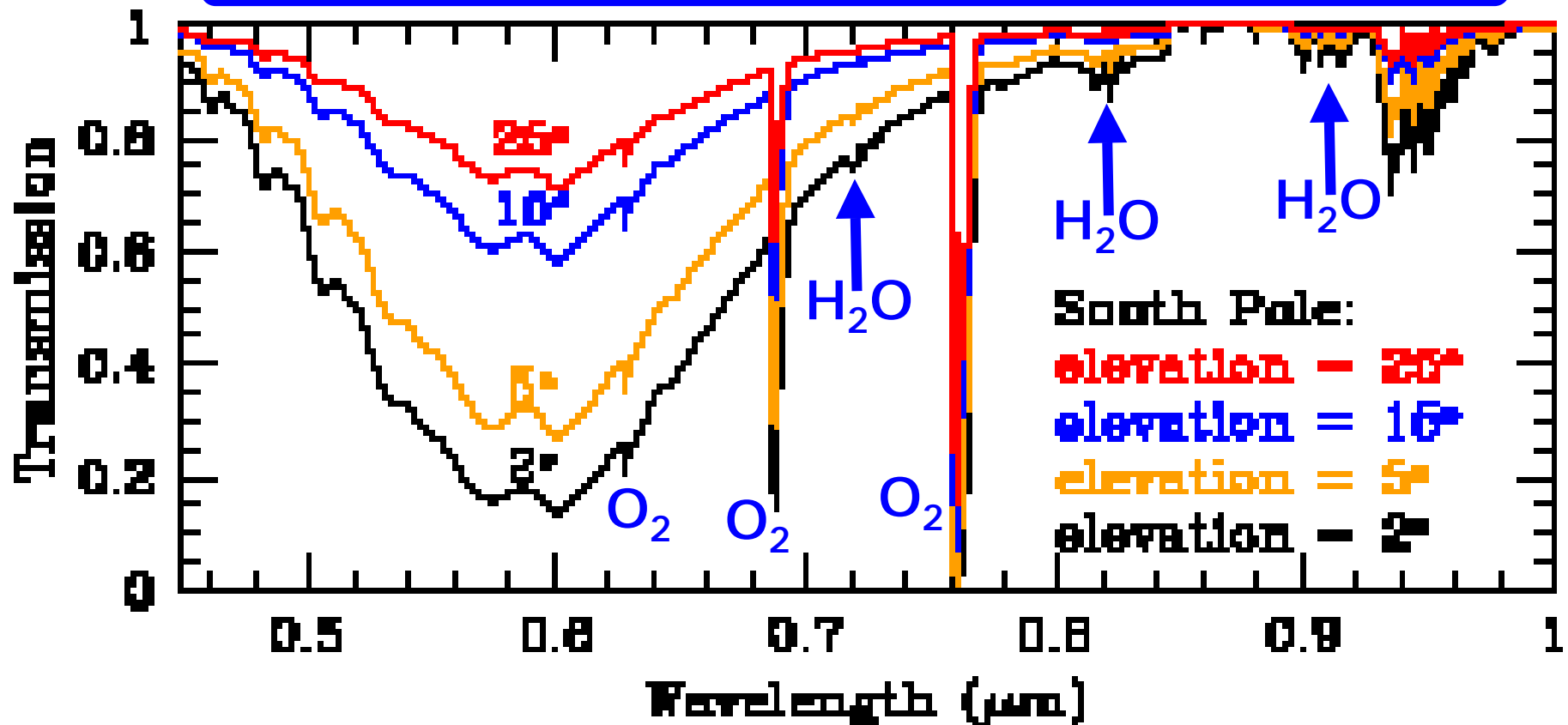
Can mount proposed small telescope on existing AST/RO telescope for guiding



see "A. Stark et al, "The Antarctic Submillimeter Telescope and Remote Observatory (AST/RO)", Pub. Astron. Soc. Pac., 113, 567, 2001.

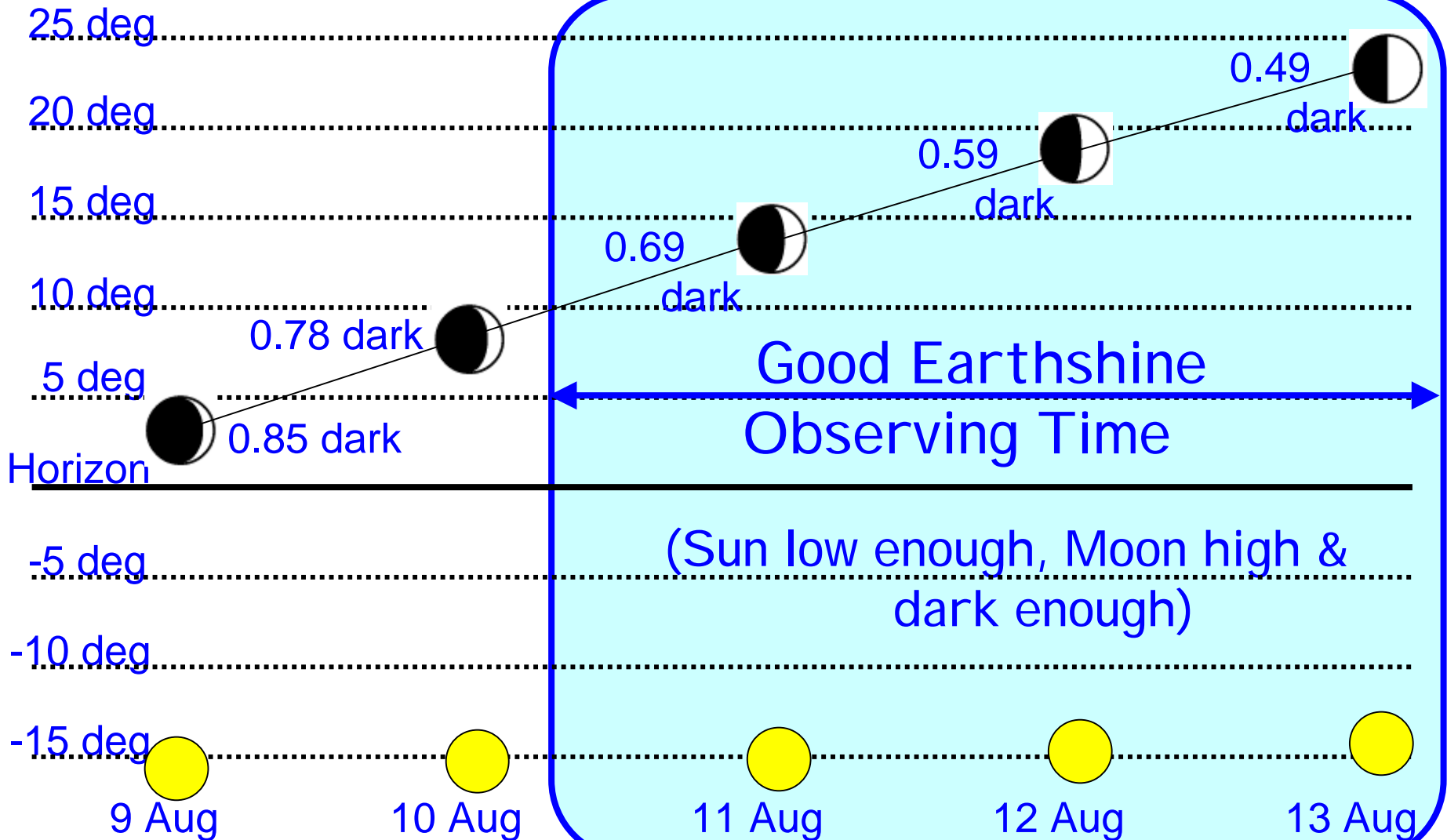
SP Dryness Helps in Sensing Earthshine Water Bands

Model atmospheric transmission: weak water bands at South Pole, but must have adequate moon elevation

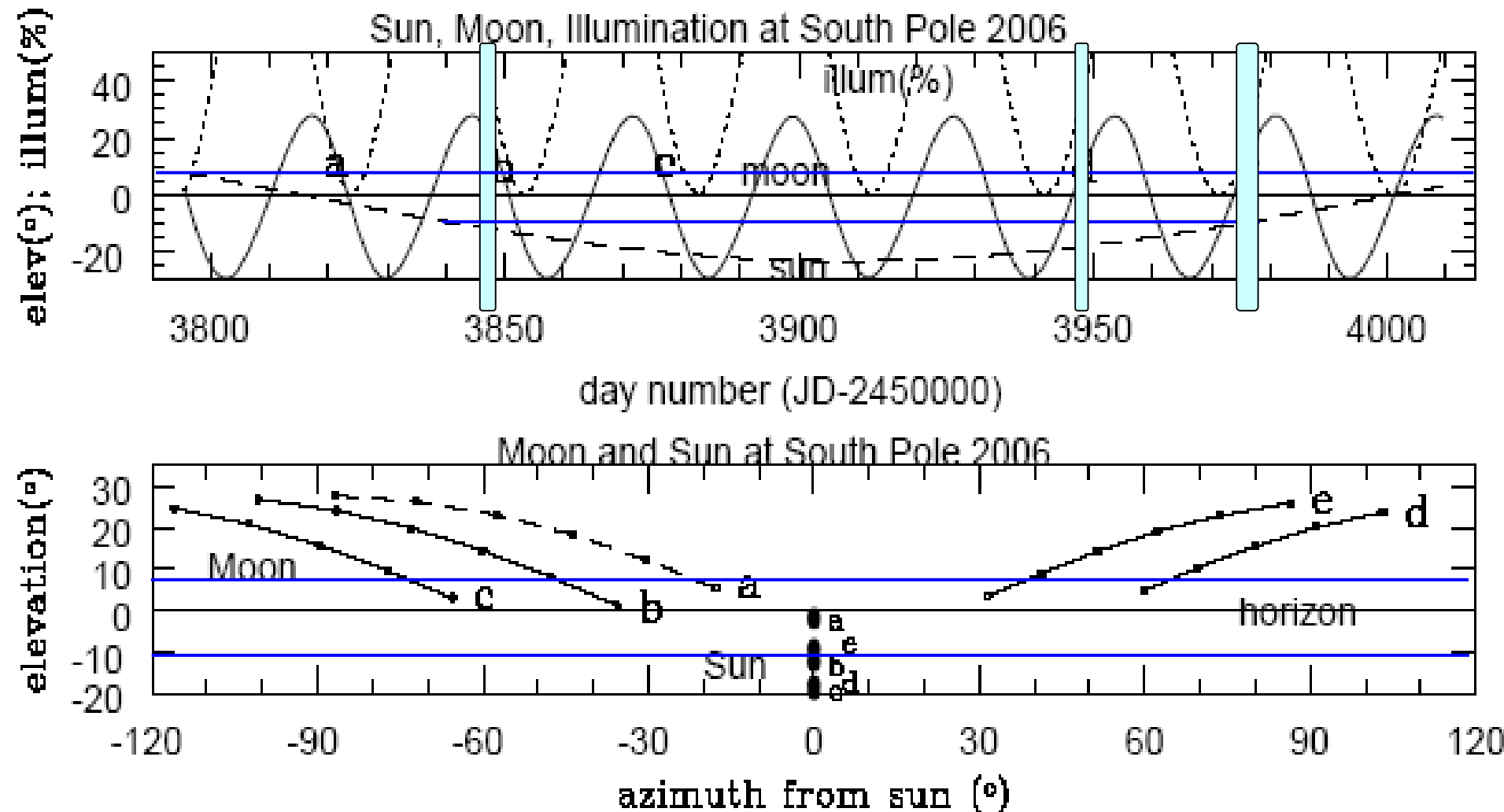


South Pole Earthshine Visibility

One Favorable 2005 Apparition

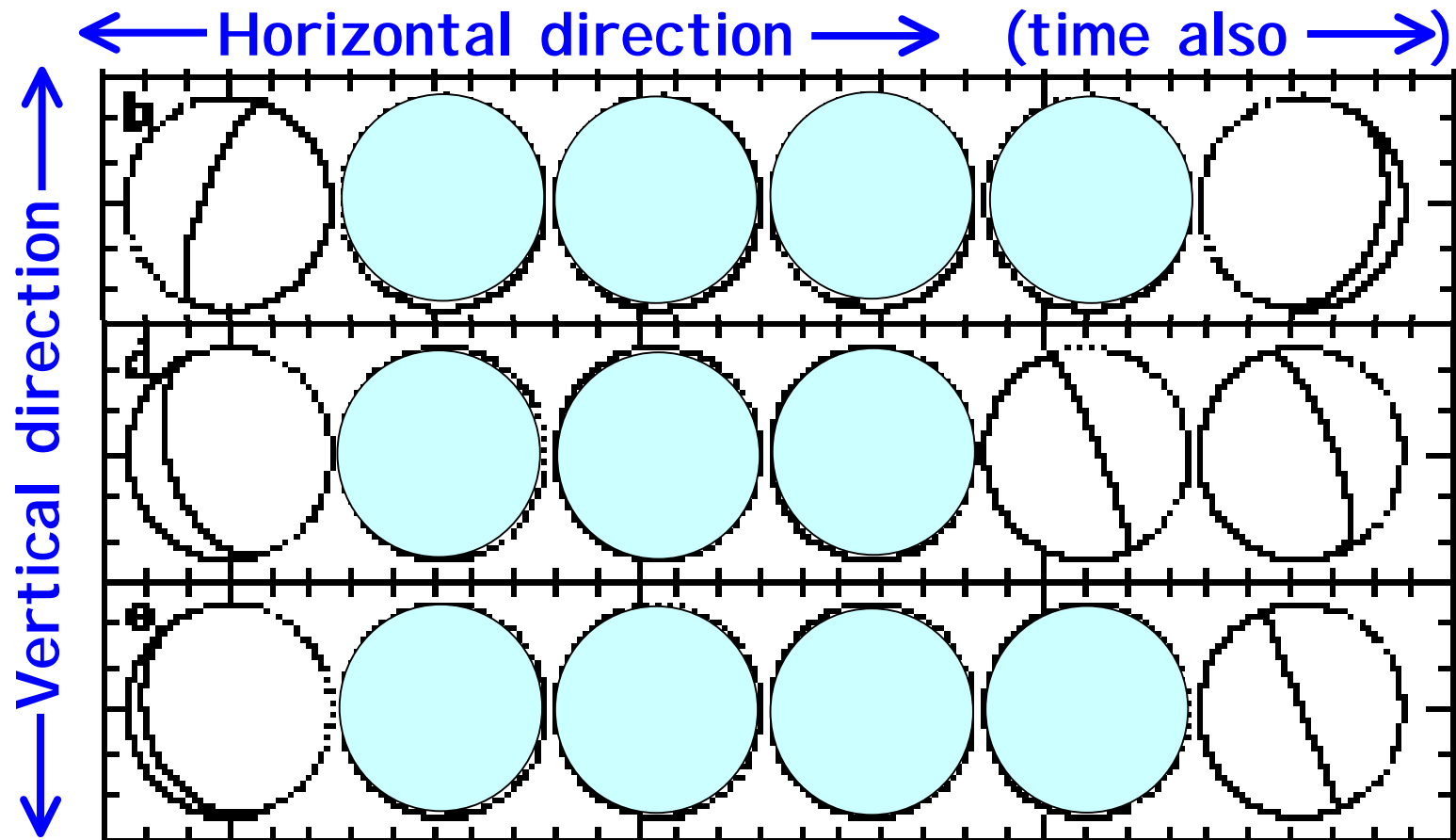


Example: Observing Cases in 2006



Apparitions a-e shown in time (upper graph) and space (lower). Most favorable times (during b,d,e) are colored in. (Date Selection Criteria: Sun > 10 degrees below horizon, Moon > 8 degrees elevation, <50% illumination [not gibbous].)

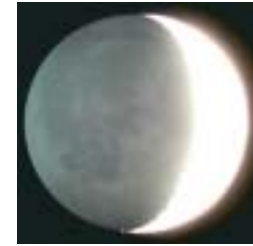
Orientations of Terminator Each 24h at Favorable 2006 Apparitions



Colored moons -- high & dark enough, with sun low enough



Summary



- Observing the Earth and its changing whole-planet-face spectrum helps us interpret visible-light data we will gather on extrasolar planets with the coronagraphic Terrestrial Planet Finder
- A South Pole location is crucial to getting continuous 24-hour coverage for several consecutive days with a single instrument
- We have access to an observational facility and can conduct relatively automated operations using a commercial spectrograph
- Anticipated results will reveal the effects of the rotating Earth, its land and sea areas, its changing weather patterns, and even changes in albedo with implications for climate change research
- This experiment is easy to understand and an excellent project to build public interest in science